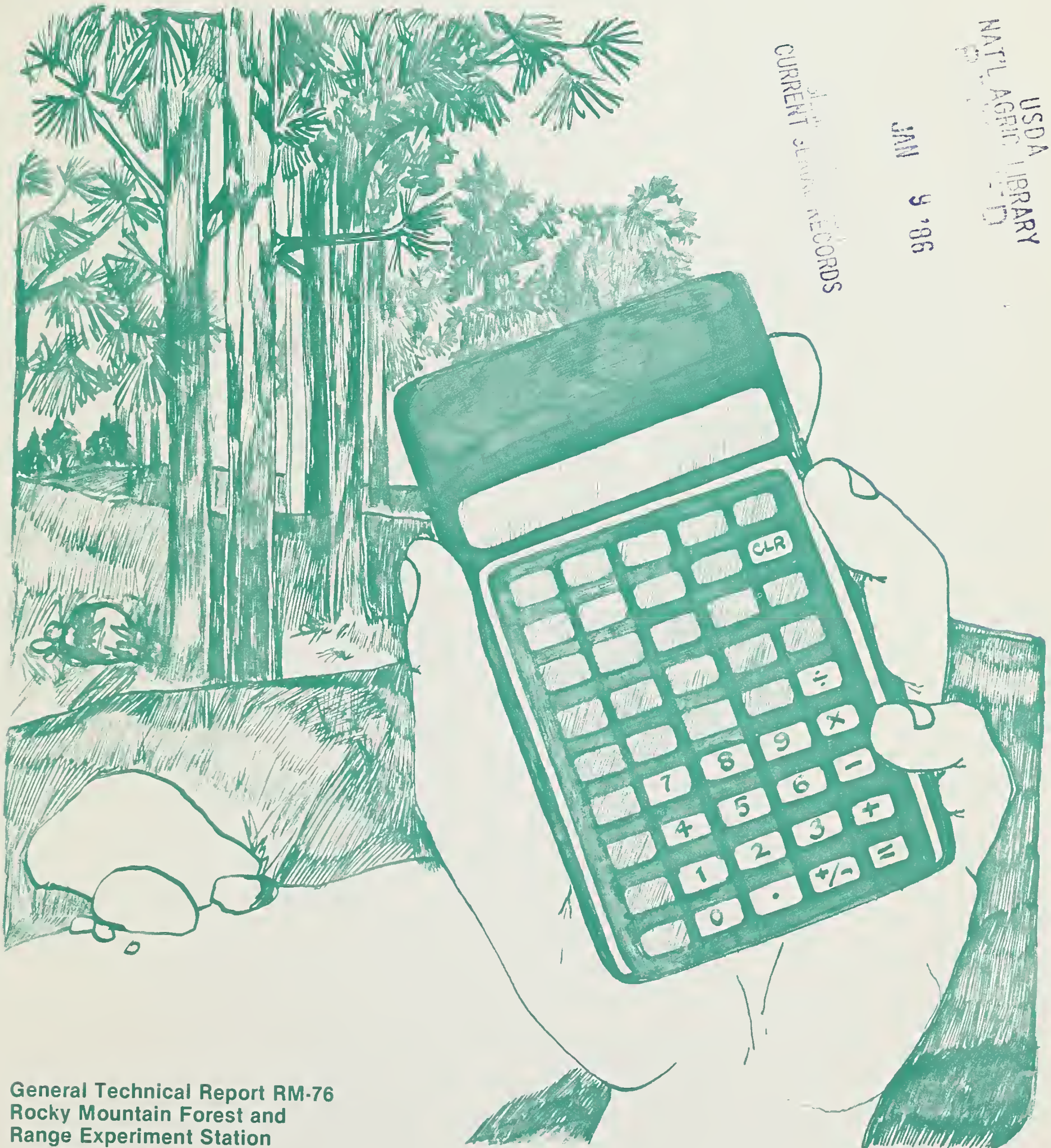
Hand-Held-Calculator Programs for the Field Forester

Wayne D. Shepperd



General Technical Report RM-76
Rocky Mountain Forest and
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Abstract

A library of programs written for hand-held, programmable calculators is described which eliminates many of the computations previously done by hand in the field. Programs for scaling aerial photos, variable plot cruising, basal area factor gauge calibration, and volume calculations are included.

Plant a tree! Mark the 75th birthday of the Forest Service by giving a living gift to future generations.

USDA Forest Service
General Technical Report RM-76

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Errata for

USDA Forest Service General Technical Report RM-76

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by Wayne D. Shepperd

On page 5, under "Example," the first line should read:

Positive slope percent to tip = 40.

On page 12, under "Formulas Used," second column, first equation should read:

$$\text{acreage} = \frac{(\text{scale of measured area})^2}{6,272,640} \times \text{photo area in square inches}$$

Contents

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Introduction

The increased availability of small, hand-held, programmable calculators has brought the computational power of computers to individual users. These machines offer many advantages. They are small, inexpensive, easy to use, require no special programming skills, and are rugged enough for field use. Newer models store and execute programs containing more than 2,000 steps.

The programs presented here are designed to help the field forester use a programmable calculator to gather and analyze data in field situations. Tedious or complicated math operations are programmed and stored on magnetic cards, which eliminates the need for tables, charts, and reference sources, and reduces computational errors. Knowledge of higher math or programming is not required to run programs.

Foresters working in the field can use these programs to perform calculations used in gathering forest inventory information, estimating tree volumes, and interpreting aerial photos. The amount of time saved by using a programmable calculator can easily pay for it in a short period of time. Calculations which normally require use of large computers, or extensive office computation, can be performed in the field, making the results immediately available.

The programs in this publication are written in outline form and are not specific to any particular brand of calculator. However, a calculator with 200 or more program steps is desirable. The programs are presented in order of complexity, so the user is gradually introduced to more advanced programming techniques.

Calculator Requirements

Several features common to most programmable calculators are necessary to use these programs:

1. User defined keys which execute a series of program steps when pressed.
2. Internal subroutine capability in which a series of program steps are executed when called by a program instruction.
3. Capability of performing trigonometric calculations in the degree mode.
4. At least 20 addressable data memories.
5. Capability of conditional branching (example: IF $a \geq b$ GO TO STEP 24).
6. SET/CLEAR FLAG operations.

Explanation of Terminology

The reader must have a working knowledge of the subject matter and be somewhat familiar with the programming procedures of the calculator to be used. Some terminology and computational techniques used in the program outlines are not identical to those used by calculator manufacturers. An explanation of these follows.

Key.—A user defined function key used to enter data or perform calculations in the proper sequence during program execution. Up to 10 keys labeled **A** through **E** and **A′** through **E′** are used in programs presented here.

Subroutines.—Labeling and calling subroutines differ among machines. Subroutines are labeled numerically here and are called with the command CALL SUBROUTINE xx, where xx is the number of the desired subroutine.

Mathematical computation.—Notation and hierarchies differ. Algebraic notation is used here, and parentheses or equal signs are used for clarification.

Memory register operations.—Again, commands differ. In this paper, SUM 01 means add the product of the preceding program step to memory 01. STORE 02 means store the product of the preceding program step **in place of** whatever was in memory 02. RECALL 03 brings the contents of register 03 into the display register.

Program control statements.—All programs assume execution of programmed operations will begin when a user defined key or a RUN key is pressed, and will continue until a STOP statement or the end of program memory is encountered. RETURN is used to continue execution after a subroutine. The next step processed is the one following the statement containing the CALL

SUBROUTINE xx command. CHANGE SIGN commands the calculator to change the algebraic sign of the number in the display register. Conditional branching operations are listed as IF statements. For example, IF $a \geq b$ GO TO 120. This means that, if **a** is greater than or equal to **b**, go to step 120, otherwise continue with the next step. The INITIALIZE PROGRAM instruction at the beginning of most program outlines can be a part of the program or done manually just prior to program execution. All data registers and flags should be cleared, and the program pointer reset to step 0 in this operation.

More efficient programming techniques could have been used in programs presented here, but in the interest of clarity and universal application, they were structured for easy translation. Most of the programs can easily be adapted for use on smaller machines, since they were written using a format, which allows programs to be subdivided into two or more programs to fit machines with smaller program memories.

In addition to a program outline, examples are provided to help correct mistakes when the programs are first put into the calculator. The formulas used in each program are included along with an explanation of the calculations performed in each subroutine. These will also aid in transferring the programs to other machines, or making modifications to fit a user's local needs. Operating instructions are given with each program to aid future nonprogramming users.

Slope to Horizontal Distance

This program converts slope distance to horizontal distance and computes the vertical rise. Data entry can be slope distance, in meters, chains, or feet, and decimal degree angle, topographic angle, or percent slope. Output distances will be in the same form as input distances.

Formulas Used

Assuming that the slope angle will vary from 0° to 90°, percent slope can be converted to degrees as follows:

$$\text{Arctan}\left(\frac{\%\text{ slope}}{100}\right) = \text{degree slope angle}$$

Topographic (1:66) slope angle also can be converted to degrees using the same relationship:

$$\text{Arctan}\left(\frac{\text{Topo. slope}}{66}\right) = \text{degree slope angle}$$

Knowing the degree slope angle, slope distance can be converted to horizontal distance by:

$$\cos(\text{degree slope angle}) \times \text{slope distance} = \text{horizontal distance}$$

Vertical rise can then be obtained by:

$$(\text{horizontal distance}) \times \tan(\text{degree slope angle}) = \text{vertical rise}$$

Program Description

User defined keys perform the following functions:

A Stores slope distance.
B Inputs and stores degree slope angle.
C Inputs percent slope angle; computes and stores degree slope angle.
D Inputs topographic slope angle; computes and stores degree slope angle.
E Computes horizontal distance and vertical rise.

User Instructions

1. Initialize program.
2. Enter slope distance, press **A**.
3. Enter degree slope angle, press **B**.
   or, Enter percent slope, press **C**.
   or, Enter topographic slope angle, press **D**.
4. Press **E**, observe horizontal distance.
5. Press **RUN**, observe vertical rise.
6. Go to step 2 and repeat if desired.

Example

For a slope distance of 100:

Slope angle	Horizontal distance	Vertical rise
10°	98.48	17.36
10%	99.50	9.95
10 topo.	98.87	14.98

Program Outline

Key	Description
A	Enter slope distance STORE 01 STOP
B	Enter degree slope angle STORE 02 STOP

C Enter percent slope angle, compute degree angle

$$\text{Arctan}\left(\frac{\%\ \text{slope}}{100}\right) = \text{degrees}$$

STORE 02
STOP

D Enter topographic (1:66) slope angle, compute degree angle

$$\text{Arctan}\left(\frac{\text{topo. slope}}{66}\right) = \text{degree angle}$$

STORE 02
STOP

E Compute horizontal distance and vertical rise
cos (RECALL 02) x RECALL 01 =
STOP
x tan (RECALL 02) =
STOP

Data Registers Used

01 = Slope distance
02 = Slope angle in degrees

Basal Area Computation

This program is designed to provide either field or office computation of basal area (BA), in square feet, given tree diameters at breast height (d.b.h.), in inches and tenths. To avoid repetitive entering of the decimal point, d.b.h. x 10 may also be entered. Results computed are: total BA of all d.b.h.'s entered, and average d.b.h. (figured from the average BA). A basal area also may be entered, and the machine will calculate the d.b.h of that BA. To be compatible with tables and other computer calculated basal areas, the following formula was used.

$$\text{BA} = \text{d.b.h.}^2 \times 0.005454$$

Program Description

After each tree diameter has been entered using key **A** or **B**, subroutine 01 is called to calculate the basal area, sum the result in an accumulator register, and increment a counter by one. Key **C** recalls the accumulated basal area. Key **D** calculates the average d.b.h. from the average basal area using the formula:

$$\text{Average d.b.h.} = \sqrt{\frac{\frac{\Sigma \text{BA}}{n}}{0.005454}}$$

User Instructions

1. Initialize program.
2. Enter d.b.h., push **A**, or enter d.b.h. x 10, push **B** (display shows BA). After all d.b.h.'s are entered:
3. Push **C** for total BA.
4. Push **D** for average d.b.h. Note: More d.b.h.'s can be entered, after pushing **C** and **D**, if desired.
5. For a new set of d.b.h.'s, go to step 1 and repeat. To find out how many d.b.h.'s have been entered, push **RCL** 02.

Example

d.b.h.	BA
10.2	0.5674
11.5	0.7213
12.6	0.8659
9.5	0.4922
Total BA	= 2.6468
Average d.b.h.	= 11.0148

Program Outline

Key	Description
	INITIALIZE PROGRAM
A	Enter d.b.h. CALL SUBROUTINE 01 STOP
SUBROUTINE 01	Calculate BA d.b.h.^{2} x 0.005454 = BA STORE 03 SUM 01 1 SUM 02 RECALL 03 RETURN
B	Enter d.b.h. x 10 $\frac{\text{d.b.h. x 10}}{10}$ = d.b.h. CALL SUBROUTINE 01 STOP
C	Display total BA RECALL 01 STOP

D — Calculate average d.b.h.

$$\frac{\frac{\text{RECALL 01}}{\text{RECALL 02}}}{0.005454} = \text{d.b.h.}^2$$

$\sqrt{\text{d.b.h.}^2}$

STOP

Data Registers Used

01 = BA sum

02 = Number of entries

03 = Individual tree BA

Tree Heights

This program allows easy field computation of tree heights where adjustments in calculations are necessary because of steep slopes, positive base angles, or conditions that prohibit sighting a tree from standard slope distances.

Program Description

Slope percent clinometer readings are entered in routines **A**, **B**, and **B′** and converted to degree angles using the following formula:

$$\text{Arctan}\left(\frac{\%\ \text{slope}}{100}\right) = \text{degree slope}$$

An angle is considered negative when the base of the tree is below a horizontal line from the viewer to the tree (fig. 1). When the tree base is above this line, the angle is considered positive (fig. 2). Both negative and positive angles to the base of the tree may be entered.

In both cases, **A** is equal to 90° minus $\mathbf{B_1}$, and the height of the tree (**b**) is calculated in subroutine C by:

$$b = \frac{a \sin B}{\sin A}$$

where **a** is the distance from the viewer to the tree base. The slope to the base of the tree is limited only by the capability of the instrument, since slope adjustment tables are unnecessary. The program can be modified for use with a topographic (1:66) scaled clinometer or abney level by changing the constant in the percent slope conversion formula from 100 to 066.

User Instructions

1. Initialize program.
2. Enter slope percent to tip, press **A**.
3. Enter slope percent to base.
   If positive, press **B′**.
   If negative press **B**.
4. Enter slope distance to base of tree, press **C**.
5. Observe tree height.
6. Go to step 1 and repeat as needed.

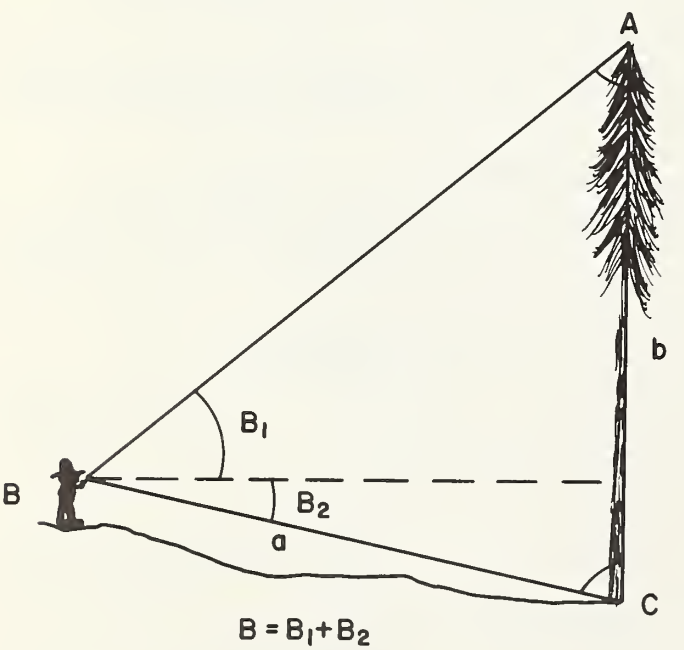

Figure 1.—Measuring tree heights where a negative base angle (B_2) occurs.

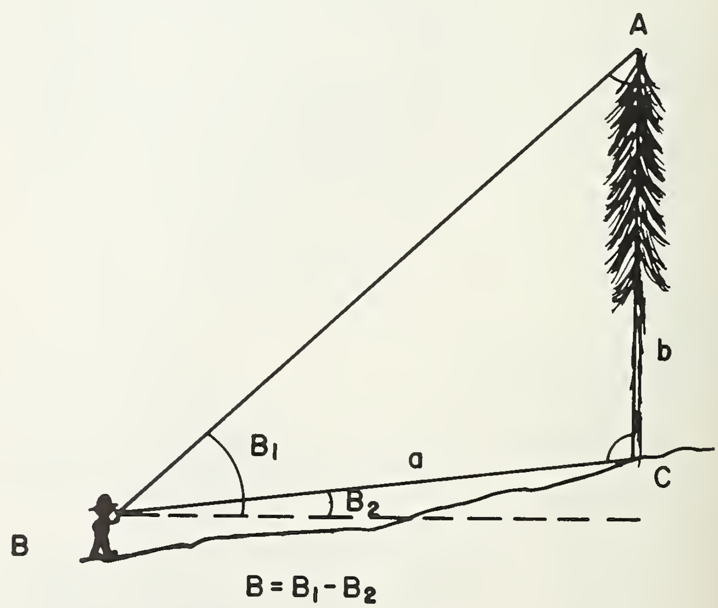

Figure 2.—Measuring tree heights where a positive base angle (B_2) occurs.

Example

Positive slope percent to base	= 40.
Negative slope percent to base	= 20.
Distance to tree	= 56.
Computed height	= 32.9
Positive slope percent to tip	= 40.
Positive slope percent to base	= 20.
Distance to tree	= 56.
Computed height	= 10.9

Program Outline

Key **Description**

INITIALIZE PROGRAM

A Enter slope percent to tip (B_1)

$$\text{Arctan}\left(\frac{B_1}{100}\right) = B_1 \text{ in degrees}$$

STORE 01
STOP

B Enter negative percent slope to base (B_2)

$$\text{Arctan}\left(\frac{B_2}{100}\right) = B_2 \text{ in degrees}$$

B_2 + RECALL 01 = B
STORE 02
STOP

B′ Enter positive percent slope to base (B_2)

$$\text{Arctan}\left(\frac{B_2}{100}\right) = B_2 \text{ in degrees}$$

B_2 – RECALL 01 = –B
CHANGE SIGN
STORE 02
STOP

C Enter slope distance (a); calculate tree height

$$\frac{a\,(\sin\,(\text{RECALL } 02))}{\sin\,(90 - \text{RECALL } 01)} = \text{tree height}$$

STOP

Data Registers Used

01 = B_1

02 = $\hat{B}$

Adequacy of Sample Test

This program allows the user to enter a set of data values and test for the size of sample needed to adequately estimate the population variation at a given confidence level. It is very useful in a field situation to check to see if a sample of adequate size has been taken before leaving the site.

Formulas Used

Snedecor and Cochran (1967) give the following formula for determining the number of samples needed, based on preliminary sample data:

$$N = \frac{4\hat{\sigma}^2}{L^2}$$

where:

N = estimated sample size needed
$\hat{\sigma}^2$ = variance of preliminary sample
L = allowable error of the sample mean in sample units. In this program, L is expressed as a proportion of the mean

The variance of the preliminary sample data is calculated using the following formula:

$$\hat{\sigma}^2 = \frac{\sum_{i=1}^{n} X_i^2 - \frac{\left(\sum_{i=1}^{n} X_i\right)^2}{n}}{n-1} = \frac{\sum_{i=1}^{n} X_i^2 - n\bar{X}^2}{n-1}$$

where **n** is equal to the size of the preliminary sample. This formula is based on a 95% level of confidence, which means that there is a 5% chance that the population mean will exceed the allowable error limit (L) when a sample of size N is taken.

Program Description

A Enters sample data and accumulates statistical data for sum, mean, and variance.
B Prints and labels number of data points entered and sum.
C Prints and labels mean.
D Calculates, prints, and labels variance.
E Enters allowable error, and calculates the sample size needed to be within that error limit. Labels and prints the results.

User Instructions

1. Initialize program.
2. Enter data value, press **A**.
3. Repeat step 2 until all data values are entered.
4. Press **B** to calculate sum.
5. Press **C** to calculate mean.
6. Press **D** to calculate variance.
7. Enter the allowable error desired as a percent of the mean (e.g., enter 0.05 = ± proportion of mean allowed). Press **E** to calculate the sample size needed to satisfy the allowable error.
8. Repeat step 7 if desired.
9. Go to step 1 to enter another set of data.

If the preliminary sample is inadequate to meet the allowable error, take additional observations and retest for adequacy.

Example

Preliminary Observations

10.
20.
15.
18.
12.
14.
18.
12.
14.
14.
16.
10.

Number of observations =	12.	= n
Sum =	173.	= Σ
Mean =	14.4	= $\bar{X}$
Variance =	10.0	= S^2
Allowable error =	0.05	
Sample size needed =	77.6	= N

Based on the preliminary observations, 78 observations are needed to adequately sample the population at a 5% confidence level.

Program Outline

Key	Description
	INITIALIZE PROGRAM
A	Enter X_i SUM 01 X^2 SUM 02 1 SUM 03 STOP
B	Calculate sum RECALL 01 STOP
C	Calculate mean $\frac{\text{RECALL 01}}{\text{RECALL 03}} =$ STORE 04 STOP
D	Calculate variance $\frac{(\text{RECALL 02}) - (\text{RECALL 03}) \times (\text{RECALL 04})^2}{(\text{RECALL 03}) - 1} =$ STORE 05 STOP
E	Enter allowable error and calculate samples needed STORE 06 $\frac{4 \times \text{RECALL 05}}{(\text{RECALL 04} \times \text{RECALL 06})^2} =$ STOP

Data Registers Used

01 = Sum
02 = Sums of squares
03 = Number of data values
04 = Mean
05 = Variance
06 = Allowable error

Multispecies Board Foot Volumes

This program calculates board foot volumes for Engelmann spruce, lodgepole pine, ponderosa pine, and aspen. All volumes are Scribner board foot to a 6-inch top. Regression equations used to calculate volumes come from volume tables developed for the Rocky Mountains by Peterson (1961), Myers (1969), Myers and Edminster (1972), and Edminster et al. (1980). The ponderosa pine equations are for the Front Range of Colorado only. Predicted volumes generally are very good over the range of the data used to develop the regressions; however, forest specific volume tables may be more accurate locally. The intention of this program is to give foresters a means of obtaining a quick, field estimate of volumes without having to calculate manually from volume tables.

Program Description

Regression equations for Englemann spruce, lodgepole pine, and ponderosa pine take the form:

$$\text{Vol.} = a + b\,D^2H$$

where:

D = d.b.h. outside bark (in inches)
H = total height (in feet)
a,b = regression constants

In practice, two equations are used for each of the above species—one for D^2H values below a certain limit, the other for D^2H values above that limit. Regression constants and D^2H limits for the conifer species are listed below:

Engelmann spruce
- For D^2H to 12,200
  - a = − 15.14466
  - b = 0.01097
- For D^2H larger than 12,200
  - a = − 27.91343
  - b = 0.01202

Lodgepole pine
- For D^2H to 22,800
  - a = − 6.00933
  - b = 0.01202
- For D^2H larger than 22,800
  - a = − 19.76641
  - b = 0.01263

Ponderosa pine
- For D^2H to 2,830
  - Volume = 8
- For D^2H larger than 2,830
  - a = − 24.5404
  - b = 0.01149

When d.b.h. and height are entered and one of the above species' subroutines is called, by pressing **C**, **D**, or **E**, the program:

- calculates D^2H
- tests the D^2H limit for that species
- calls subroutine 01 which then calculates the volume
- stores the volume in a species total register and a grand total register
- displays the tree volume by species.

For aspen, a single logarithmic regression equation is used (Peterson 1961):

$$Y = 1.1214X_1 + 0.9427X_2 - 1.9840$$

where:
$Y = \text{Log}_{10}$ (volume to 6-inch top inside bark − 9)
$X_1 = \text{Log}_{10}$ [(d.b.h. inside bark)^2 + 36]
$X_2 = \text{Log}_{10}$ (height to 6-inch top inside bark − 8.15)
d.b.h. inside bark = 0.8954 d.b.h. outside bark + 0.3168.

When the d.b.h. and **height to a 6-inch top** are entered and the aspen subroutine is called, by pressing **E′**, the d.b.h. and height are processed directly through this routine to yield the volume.

User Instructions

If d.b.h. data will be entered from a tally sheet by diameter classes with a 0.5 midpoint (e.g., 14-inch class = 14.0 inches – 14.9 inches), press **A′**. Otherwise, enter the actual measured d.b.h. of each tree.

1. Enter d.b.h. (e.g., 8.5 or 8 if **A′** was pushed), press **A**.
2. Enter height, press **B**. Enter total tree height for all species except aspen. Enter height to a 6-inch top for aspen.
3. Press species key desired:

   C = Engelmann spruce
   D = Lodgepole pine
   E = Front Range ponderosa pine
   E′ = Aspen
4. Record volume.
5. Repeat steps 1-4 until all trees have been entered.
6. Press **B′** for grand total of all species entered.
7. Press **C′** for Engelmann spruce total volume; then, press RUN for lodgepole pine total, press RUN for ponderosa pine total, press RUN for aspen total.

Example

Results if a 10.5 d.b.h., 50-foot tree is entered for each species:

Volume	Species
45.	Spruce
60.	Lodgepole
25.	Ponderosa
91.	Aspen
222.	Total board feet

Program Outline

Key	Description
	INITIALIZE PROGRAM
A	Enter d.b.h. + RECALL 11 = STORE 01 STOP
A′	Set d.b.h. class midpoint 0.5 STORE 11
B	Enter height, and calculate D^2H STORE 02 x (RECALL 01)^2 = STORE 03 STOP
Enter species	
C	Engelmann spruce IF RECALL 03 ≥ 12,200: 0.01202 STORE 04 27.91343 STORE 05 otherwise: 0.01097 STORE 04 15.14466 STORE 05 CALL SUBROUTINE 01 SUM 06 SUM 10
SUBROUTINE 01	Calculate conifer volumes RECALL 04 x RECALL 03 – RECALL 05 = RETURN
D	Lodgepole pine IF RECALL 03 ≥ 22,800: 0.01263 STORE 04 19.76641 STORE 05 otherwise: 0.01202 STORE 04 6.00933 STORE 05 CALL SUBROUTINE 01 SUM 07 SUM 10 STOP
E	Front Range ponderosa pine IF RECALL 03 ≤ 2,800: 8 SUM 08 SUM 10 STOP otherwise: 0.01149 STORE 04 24.5404 STORE 05 CALL SUBROUTINE 01 SUM 08 SUM 10 STOP
E′	Aspen (RECALL 01 x 0.8954 + 0.3168)^2 + 36 = Log_{10} x 1.1214 = STORE 12 RECALL 02 – 8.15 = Log_{10} x 0.9427 – 1.9840 + RECALL 12 = Antilog_{10}, or 10^x = + 9 = SUM 09 SUM 10
B′	Display total volume RECALL 10 STOP
C′	Display species total RECALL 06 STOP
RUN	RECALL 07 STOP
RUN	RECALL 08 STOP
RUN	RECALL 09 STOP

Data Registers Used

01 = d.b.h.
02 = Height
03 = D^2H
04 = b, regression function
05 = a, regression function
06 = Engelmann spruce volume total
07 = Lodgepole pine volume total
08 = Ponderosa pine volume total
09 = Aspen volume total
10 = Grand total volume
11 = 0.5 for d.b.h. midpoint
12 = Temporary aspen calculation

BAF Gauge Calibration

This program enables the user to calibrate or construct an angle gauge for variable plot cruising using any basal area factor (BAF). If any two of the following variables are known, the program will calculate the third: (1) BAF, (2) width of cruising gauge, or (3) sighting distance (distance from eye to gauge).

A wedge of known width can be converted to any BAF simply by computing the distance it is held from the eye and placing knots in the cord denoting each distance. Existing gauges can be calibrated and checked for accuracy. Or if desired, the BAF of one's thumb can be determined eliminating the need for a gauge.

Formulas Used

The BAF for basal area in square feet per acre can be found using the following formula (Husch 1963):

$$BAF = 43{,}560 \times \sin^2\Theta/2$$

where:

Θ = angle covered by the gauge when viewed at a given distance.

The trigonometric model in figure 3 applies.
Angle A can be determined from the BAF formula as follows:

$$BAF = 43{,}560 \times \sin^2 A$$

$$\sin A = \sqrt{\frac{BAF}{43{,}560}}$$

$$A = \text{Arc}\sin\sqrt{\frac{BAF}{43{,}560}}$$

Right triangle solutions for a and b are:

$$A = \frac{a}{\tan A} = \text{sighting distance}$$

$$a = b\tan A$$
$$2a = \text{width of angle gauge}$$

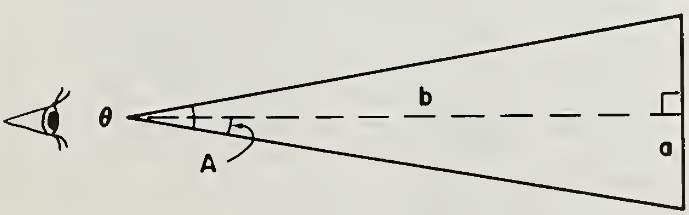

Figure 3.—Trigonometric model for basal area factor gauge calibration.

If BAF is not known, A is found by

$$\frac{a}{b} = \tan A$$

$$A = \text{Arctan}\left(\frac{a}{b}\right)$$

Program Description

User defined keys **A, B,** and **C** are used to enter and store BAF, gauge width, and sighting distance, respectively. Flags are set when each of these variables are entered. Pressing **A′** calculates BAF, given sighting distance and gauge width. **B′** calculates gauge width given BAF and sighting distance. **C′** calculates sighting distance given BAF and gauge width. Set flag tests will not allow computation of any of these variables if the proper data has not been entered. Internal subroutine 02 is called by **B** and **C** to calculate angle A. Subroutine 01 is called to flash the display if the necessary data have not been entered.

User Instructions

1. Initialize program
2. Enter **any two** of the following:
   a. BAF, press **A**.
   b. Gauge width, press **B**.
   c. Sighting distance, press **C**.
3. Press **A′** to compute BAF.
   B′ to compute gauge width.
   C′ to compute sighting distance.
4. Go to 2 and repeat as needed.

Example

BAF = 10
Gauge width = 0.75 inch
String length = 24.75 inches

Program Outline

Key	Description
	INITIALIZE PROGRAM
A	Enter BAF STORE 01 SET FLAG 01 STOP
B	Enter gauge width ÷ 2 = STORE 02 SET FLAG 02 STOP

C — Enter string length
STORE 03
SET FLAG 03
STOP

A′ — Calculate BAF
IF FLAG 02 is not set:
CALL SUBROUTINE 01
IF FLAG 03 is not set:
CALL SUBROUTINE 01

$$\left[\sin\left[\text{Arctan}\left(\frac{\text{RECALL 02}}{\text{RECALL 03}}\right)\right]\right]^2 \times 43{,}560 =$$

STOP

SUBROUTINE 01 — Indicate error by flashing display
$\sqrt{-1}$
STOP

B′ — Calculate gauge width
IF FLAG 01 is not set:
CALL SUBROUTINE 01
IF FLAG 03 is not set:
CALL SUBROUTINE 01
CALL SUBROUTINE 02
RECALL 03 x tan (RECALL 04)
x 2 =
STOP

SUBROUTINE 02

$$\text{Arc sin}\sqrt{\frac{\text{RECALL 01}}{43{,}560}} =$$

STORE 04
RETURN

C′ — Calculate string length
IF FLAG 01 is not set:
CALL SUBROUTINE 01
IF FLAG 02 is not set:
CALL SUBROUTINE 01
CALL SUBROUTINE 02

$$\frac{\text{RECALL 02}}{\tan(\text{RECALL 04})} =$$

STOP

Data Registers Used

01 = BAF
02 = Gauge width x 2
03 = String length
04 = Angle A

Limiting Distance

This program calculates the limiting distance from plot center to a tree of any d.b.h. in a variable-radius cruise plot. It is especially useful when a precise determination is needed for trees not easily seen with a prism or cruising wedge, or if adjustments for steep slopes are necessary.

If a tree appears to be borderline (i.e., it is hard to tell if the tree is in or out of the plot using a BAF gauge or prism), the user proceeds as follows:

1. Measure the d.b.h. of the tree in question.
2. Measure the distance from the center of the tree to the plot center (SD) as shown in figure 4.

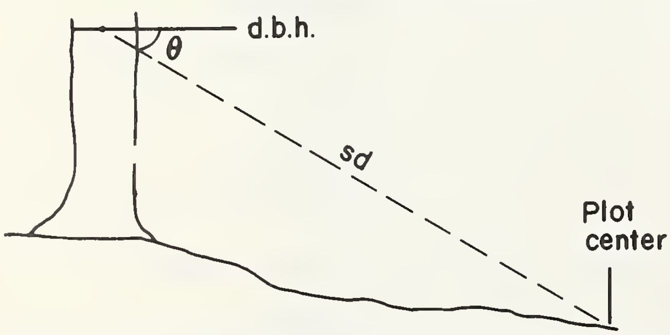

Figure 4.—Measuring the distance from the center of the tree to plot center.

3. Measure the slope from the center of the tree to plot center (angle Θ) in degrees or percent.
4. Using this information, the calculator will compute the limiting distance for a tree of the measured d.b.h., compute the actual horizontal distance from the center of the tree to plot center, and determine whether the tree is "in" or "out" of the variable radius plot.

Formulas Used

In a variable radius plot, the plot radius is dependent upon the diameter of each tree to be measured. The d.b.h. of a tree multiplied by a plot radius factor for a given BAF gives the limiting distance or plot radius for that d.b.h. Any tree of the same d.b.h. located beyond this distance from the plot center is considered out and should not be measured. A regression analysis was performed on plot radius and basal area factors listed by Dilworth and Bell (1971) to obtain the following relationships:

$$\text{Plot radius factor} = \sqrt{\frac{1}{y}}$$

when y = 0.0132232494 x BAF.

Program Description

This predicts the plot radius factor for a given BAF, in key **A**. The plot radius factor is multiplied by d.b.h. in key **B** to obtain limiting distance.

Actual slope distance is input using key **C** and, given the angle of slope, (Θ) used in **D** to calculate the actual horizontal distance as follows:

$$\cos \Theta \times \text{slope distance} = \text{horizontal distance}$$

Percent slope input using key **D′** is converted to a degree angle before being processed in the above formula.

Key **E** determines whether a tree is in or out of the plot by algebraically subtracting actual horizontal distance from limiting distance and attempting to take the square root of the result. If the result is negative (i.e., the tree is "out"), the routine is aborted and the display flashes. If the tree is "in," the routine completes, and the distance by which the tree is inside the plot is shown.

This computational technique not only adjusts for slope, but also accounts for leaning or crooked trees because limiting distance is assumed to be the horizontal distance from the center of the tree at d.b.h. to the plot center.

User Instructions

1. Initialize program.
2. Enter BAF, press **A**, observe plot radius factor.
3. Enter d.b.h., press **B**, observe limiting distance.
4. Enter measured slope distance (SD), press **C**.
5. Enter slope angle (Θ):
   - if in degrees, press **D**.
   - if in percent slope, press **D′**.
   - observe actual horizontal distance.
6. Press **E**. If the display flashes, the tree is "out" and not tallied. If tree is "in," the display will indicate the distance the tree is inside the limit.

Example

BAF = 40
d.b.h. = 12.5 inches
Computed limiting distance = 17.19 feet
Slope distance = 18.0 feet
Slope = 30% or 16.7°
Computed horizontal distance = 17.24 feet
Tree is "out" by 0.05 foot

Program Outline

Key	Description
	INITIALIZE PROGRAM
A	Enter BAF, calculate plot radius factor $\sqrt{\dfrac{1}{\text{BAF} \times 0.0132232494}} =$ STORE 01 STOP
B	Enter d.b.h., calculate limiting distance d.b.h. x RECALL 01 = STORE 02 STOP
C	Enter slope distance STORE 03 STOP
D	Enter slope in degrees, calculate horizontal distance COS (slope in degrees) x RECALL 03 = STORE 04 STOP
D′	Enter percent slope, calculate horizontal distance $\text{Arctan}\left(\dfrac{\%\ \text{slope}}{100}\right) =$ GO TO D STOP
E	Determine if the tree is in or out RECALL 02 – RECALL 04 = X $\sqrt{X}$ X^2 STOP

Data Registers Used

01 = Plot radius factor
02 = Limiting distance
03 = Slope distance
04 = Actual horizontal distance

Photo Work Program

This program[2] performs all calculations necessary to determine photo scales, stand scales, and stand acreages for inventory and sale layout work, using U.S. Geological Survey topographic maps, aerial photos, and dot grids or planimeter.

Distances are measured between two points at the same elevation using both the map and the photo. The program calculates a photo scale at that elevation and automatically adjusts it to a prescribed standard elevation for the effective area of the photo.

Once enough measurements have been taken to establish a reliable photo scale, the program can compute acreages for any portion of a photo's effective area. A planimeter reading or dot count is input along with the photo scale, photo scale elevation, and the mean elevation of the measured area. The program computes an adjusted scale for the measured area and uses it to determine the acreage.

Formulas Used

A photo scale at elevation A is computed by:

$$\frac{MD}{PD} \times MSF = \text{calculated scale}$$

where:

MD = Distance between two points at elevation A measured on a map

PD = Distance between the same two points measured on a photo

$$MSF = \text{Map scale factor} = \frac{1}{\text{map scale}}$$

(e.g., a topographic map with a scale of 1/24,000 would have a MSF = 24,000)

This computed scale at elevation A can be adjusted to a standard elevation B as follows:

$$(B - A) \times K = \text{change in scale}$$

This can be a positive or negative change.

K = scale change factor which is dependent upon the focal length of the lens used in the aerial photography and is calculated by:[3]

$$K = \frac{12}{\text{focal length of lens in inches}}$$

The change in scale is algebraically added to the calculated scale to obtain the adjusted scale at elevation B.

[2]*This program was originally written by Paul Ries, Routt National Forest, and is presented here with his permission.*

[3]*Derived from equations presented in Rayner and Schmidt (1963).*

Once a standard photo scale at elevation B has been determined, acreages of a portion of the photo at any elevation can be calculated. First, a scale for area to be measured is calculated by adjusting the standard scale to the average elevation of the area to be measured. This scale is then multiplied by the area (in square inches) measured on the photo to obtain the number of square inches represented on the ground by the measured area. The result is then divided by the number of square inches in an acre to get the acreage of the area. Therefore:

$$\text{acreage} = \frac{\text{photo area in square inches x scale of measured area}}{6{,}272{,}640}$$

Program Description

This program is essentially two programs in one. The first enables the user to determine a standard photo scale at a given elevation. The second calculates the acreage of an area measured on a photo of known scale.

User defined keys are used as follows:

- **A** Initializes program and stores a map scale of 1:24,000.
- **A′** Initializes program and stores a map scale of 1:62,500.
- **B** Stores a distance measured between two points on a map.
- **C** Inputs the measured distance between the same two points on a photo, and calculates a scale.
- **D** Stores the elevation of the measured points.
- **D′** Stores the desired standard elevation for the photo scale and adjusts the scale computed in **C** to the standard elevation.
- **B′** Stores photo scale and photo scale elevation.
- **E** Inputs dot count from a dot grid with 64 dots per square inch and converts to square inches. Inputs elevation of measured area and computes scale and acreage.

This program uses a scale change factor of 1.46 per foot of elevational change. This assumes that a camera with a lens focal length of 8.21 inches was used in the aerial photography. Program steps containing the scale change factor will need to be changed if other focal length lenses are used. Again, scale change factors for other focal lengths may be calculated by:

$$\text{Scale change factor} = \frac{12}{\text{focal length in inches}}$$

Most commercial aerial photos have the focal length in millimeters listed on the border (Example CFL208.36).

User Instructions

1. Initialize program.
2. Select topographic map scale desired:
   Press **A** for 1:24,000 scale.
   Press **A′** for 1:62,500 scale.
3. Enter map distance, press **B**.
4. Enter photo distance, press **C**. Observe unadjusted scale.
5. Enter elevation of measurement, press **D**.
6. Enter the standard elevation desired for the photo (usually the average elevation of the photo's effective area), press **D′**. The scale computed in step 5 will be adjusted to the standard elevation and displayed.
7. Steps 3, 4, and 5 may be repeated as desired. The adjusted scale will now be displayed each time **D** is pressed.

To determine acreages:

1. Enter photo scale, press **B′**.
2. Enter photo scale elevation, press **R/S**.
3. Enter: Dot count (64 dots per square inch) of measured area, press **E** or planimeter reading (in square inches), press **E′**.
4. Enter mean elevation of measured area, press **R/S**. Scale and acres of measured area will print. Display will show acres.
5. Steps 3 and 4 can be repeated as needed.

Each measured area should be within the effective area of a photo. If the desired area falls within the effective area of two or more photos, the portion occurring in each should be measured separately.

Examples

Scale calculation:

Map distance = 1.75 inches
Photo distance = 2.5 inches
Elevation = 8,500 feet
Unadjusted scale = 16,800 @ 8,500 feet
Standard elevation = 9,000 feet
Adjusted scale = 16,070 @ 9,000 feet

Acreage determination:

Photo scale = 16,000 @ 9,000 feet
Dot count = 128
or, planimeter reading = 2 square inches
Mean elevation of measured area = 9,200 feet
Scale of measured area = 1:15,708
Acreage = 78.67 acres

Program Outline

Key	**Description**
A	Initialize, 1:24,000 map scale CLEAR MEMORIES CLEAR FLAG 01 24,000 STORE 01 STOP
A′	Initialize 1:62,500 map scale CLEAR MEMORIES CLEAR FLAG 01 62,500 STORE 01 STOP
B	Enter map distance STORE 10 STOP
C	Enter photo distance and calculate unadjusted photo scale STORE 11 $\left(\frac{\text{RECALL 10}}{\text{RECALL 11}}\right)$ RECALL 01 = STORE 02 STOP
D	Enter elevation of measurement STORE 03 IF FLAG 01 is set: CALL SUBROUTINE 01 STOP
D′	Enter standard elevation STORE 04 SET FLAG 01 CALL SUBROUTINE 01 STOP
SUBROUTINE 01	Adjusts scale to standard elevation RECALL 04 - RECALL 03 = CHANGE SIGN x 1.46 = + RECALL 02 = STOP
B′	Enter photo scale and photo scale elevation STORE 05 STOP STORE 06 STOP

E	Enter dot count and elevation of measured area, calculate acreage ÷ 64 = CALL SUBROUTINE 02 STOP
E′	Enter photo area in square inches, calculate acreage CALL SUBROUTINE 02 STOP
SUBROUTINE 02	Calculates acreage and scale STORE 07 STOP (Enter elevation press RUN) – RECALL 06 = CHANGE SIGN x 1.46 = + RECALL 05 = X or scale of measured area on photo STOP (observe scale, press RUN) $\left(\frac{X^2}{6272640}\right)$ RECALL 07 = acreage STOP

Data Registers Used

01 = Map scale
02 = Unadjusted photo scale
03 = Elevation of map and photo distance measurements
04 = Standard elevation
05 = Adjusted photo scale
06 = Elevation of known photo scale used in acreage computation
07 = Measured photo area in square inches
10 = Map distance
11 = Photo distance

Spruce Variable Plot Cruising

This program brings the computational power of a large computerized inventory to the field, making possible instant reduction of cruise data and application of results. It is especially useful where no inventory information is available to write silvicultural prescriptions, to complete transportation system planning, or to perform presale layout.

With this program, the user can obtain quick summaries of board feet volumes and stocking from variable radius plot tally data. This program contains the general volume equations for Engelmann spruce, used in the multispecies board foot volume program, which was derived from data collected throughout the central Rockies (Myers and Edminster 1972). It can easily be modified for other species or other volume equations by changing subroutines 01 and 02 to include the desired equations.

To use this program, each "in" tree in a variable plot sample would be tallied on a sheet by 1 inch d.b.h. (midpoint 0.5 inch) and 10 feet total height class. The BAF used should result in several trees being tallied per point. The number of points sampled in the stand also should be noted.

Formulas Used

The midpoint of each d.b.h. class is used to compute basal area in square feet by:

$$BA = d.b.h.^2 \times 0.005454$$

For a single point, each tallied tree represents a certain number of trees per acre. This is found by dividing the BAF used by the BA of a given d.b.h. class.

$$\frac{BAF}{BA} = \text{No. of trees per acre for each tree tallied}$$

Dividing this figure by the number of plots taken results in an average trees per acre conversion factor for each tree tallied in the stand.

Given the d.b.h. class, BAF, number of plots taken, and the total number of trees tallied in that d.b.h. class, the program uses the above equations to calculate the stems per acre for that d.b.h. class. A subroutine is then called to calculate the volume in board feet Scribner rule for a tree of the given d.b.h. and height class.

$$\text{Volume} = 0.01097\ D^2H - 15.14466 \text{ for } D^2H \text{ to } 12{,}200$$
$$\text{Volume} = 0.01202\ D^2H - 27.91343 \text{ for } D^2H > 12{,}200$$

This single tree volume is then multiplied by the stems per acre computed above to give a volume per acre for the d.b.h. class and height class. D.b.h. class volumes are accumulated to yield a total volume per acre for the stand. The program is designed to work through one d.b.h. class at a time. For example, all the 10-inch class data is entered and a summary is obtained before moving on to the 11-inch class. To minimize the chance for error, the program is designed to flash the display when all the required variables have not been entered.

Program Description

A Stores d.b.h. class midpoint.
B Stores height class. Computes D^2H.
C Stores the number of trees. Computes stems per acre. Assigns proper subroutine to compute volume.
D Displays d.b.h. volume per acre and stems per acre summary. Clears stem per acre and volume registers for another d.b.h. class.
E Displays total volume per acre and total stems per acre.
A′ Stores BAF.
B′ Stores the number of plots taken.
E′ Initializes the program by clearing all memories, clearing all flags, and resetting program pointer.

Internal Subroutines

Subroutine 01—supplies proper spruce regression functions to subroutine 02 according to D^2H.
Subroutine 02—calculates volumes for Engelmann spruce.

User Instructions

1. Initialize program.
2. Enter BAF, press **A′**.
3. Enter the number of plots, press **B′**.
4. Enter d.b.h., press **A**.
5. Enter height, press **B**.
6. Enter the number of trees tallied, press **C**.
7. Observe volume per acre for trees of the given d.b.h. and height. RECALL 15 will display the stems per acre.
8. Repeat steps 7-10 until all cells for a d.b.h. class have been loaded. BAF, number of plots, d.b.h. class, and height class can be entered in any order. All must be entered prior to entering the number of trees and pressing **C**.
   After entering the above data once, the only item which **must** be entered prior to pressing **C** again is the number of trees. The program will automatically use the BAF, number of points, d.b.h., and height data still stored in memory from the last computation to process the new number of trees entered. **The user need only enter data which has changed** from the last entry and not re-enter all data for each height or d.b.h. class. However, once a d.b.h. class total has been calculated by pressing **D**, a new d.b.h. class must be entered before continuing.
9. Press **D** for the total volume per acre for that d.b.h. class. Press RUN for stems per acre total for that class.
10. Go to step 4 and begin entering a new d.b.h. class.
11. Repeat steps above until all data has been entered.
12. Press **E** for the total volume per acre in the stand. To find total stems per acre, press RUN.
13. Go to step 1 to enter data from another stand.

Example

Figure 5 is an example of a cruise tally sheet and the volumes computed from it.

Program Outline

Key	**Description**
	INITIALIZE PROGRAM
A′	Store BAF STORE 11 SET FLAG 03 STOP
B′	Store number of points STORE 13 SET FLAG 04 STOP
A	Enter d.b.h. class, calculate midpoint d.b.h. + 0.5 = STORE 01 SET FLAG 01 STOP
B	Enter height class, calculate D^2H STORE 02 (RECALL 01)^2 x RECALL 02 = STORE 03 SET FLAG 02 STOP
C	Enter number of tally trees, calculate stems per acre and volume STORE 14 IF FLAG 01 IS NOT SET: CALL SUBROUTINE 04 (This subroutine does not exist; therefore, an error results when it is called, aborting the program) IF FLAG 02 IS NOT SET: CALL SUBROUTINE 04 IF FLAG 03 IS NOT SET: CALL SUBROUTINE 04 IF FLAG 04 IS NOT SET: CALL SUBROUTINE 04 (RECALL 01)^2 x 0.005454 = X $\frac{1}{X}$ x RECALL 11 ÷ RECALL 13 x RECALL 14 = STORE 15 SUM 18 SUM 09 CALL SUBROUTINE 01 STOP

Tally sheet

BAF 50 **No. points 5**

Height	50	60	70
d.b.h. 10	•		•
d.b.h. 11	•••	•	•
d.b.h. 12		••••	
d.b.h. 13			•••

Stand volume table

Height	50	60	70	Totals	
d.b.h.				Volume	Stems per acre
10	753.8		1,156.1	1,909.9	33.3
11	2,387.2	996.8	1,198.0	4,582.0	69.3
12		4,116.4		4,116.4	46.9
13			3,785.7	3,785.7	30.2
			Total	14,394.0	179.7

Figure 5.—Example cruise tally sheet and stand volume table.

SUBROUTINE 01 — Select regression functions for volume calculations
IF RECALL 03 ≥ 12,200:
  0.01202 STORE 04
  27.91343 STORE 05
otherwise:
  0.01097 STORE 04
  15.14466 STORE 05
CALL SUBROUTINE 02
(VOLUME) x RECALL 15 = (VOLUME/ACRE)
SUM 06
SUM 10
RETURN

SUBROUTINE 02 — Calculate tree volume
RECALL 04 x RECALL 03 − RECALL 05 = (VOLUME)
RETURN

D — Display d.b.h. totals, reset memories for next d.b.h. class
RECALL 10
STORE 07
RECALL 18
STORE 08
0.0 STORE 10
0.0 STORE 18
RECALL 07
STOP
RECALL 08
STOP

E — Display grand total volume and stems per acre
RECALL 06
STOP
RECALL 09
STOP

Memory Registers Used

01 = d.b.h. class
02 = Height class
03 = D^2H
04 = First regression function
05 = Second regression function
06 = Stand volume total
07 = Temporary volume
08 = Temporary stems per acre
09 = Stand total stems per acre
10 = d.b.h. volume total
11 = BAF
12 = Not used
13 = Number of plots taken
14 = Number of tally trees
15 = Temporary stems per acre for a height class within d.b.h.
16 = Not used
17 = Not used
18 = d.b.h. stems per acre total

Literature Cited

Dilworth, J. R., and J. F. Bell. 1977. Variable probability sampling—Variable plot and three-p. 130 p. Oregon State University Book Stores, Inc. Corvallis, Oregon.

Edminster, Carleton B., Robert T. Beeson, and Gary E. Metcalf. 1980. Volume tables and point-sampling factors for ponderosa pine in the Front Range of Colorado. USDA Forest Service Research Paper RM-218, 10 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Husch, Bertram. 1963. Forest mensuration and statistics. 473 p. The Ronald Press, New York.

Myers, Clifford A. 1969. Board-foot volumes to a 6-inch top for lodgepole pines in Colorado and Wyoming. USDA Forest Service Research Note RM-157, 3 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Myers, Clifford A., and Carleton B. Edminster. 1972. Volume tables and point-sampling factors for Engelmann spruce in Colorado and Wyoming. USDA Forest Service Research Paper RM-95, 23 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Peterson, Geraldine. 1961. Volume tables for aspen in Colorado. Rocky Mountain Forest Range Experiment Station Research Note 63, 4 p. Fort Collins, Colo.

Snedecor, George W., and William G. Cochran. 1967. Statistical methods. 593 p. Iowa State University Press, Ames.

Rayner, William H., and Milton O. Schmidt. 1963. Elementary surveying. 485 p. D. Van Nostrand Company, Princeton, New Jersey.

Agriculture—CSU, Fort Collins

Shepperd, Wayne D. 1980. Hand-held-calculator programs for the field forester. USDA Forest Service General Technical Report RM-76, 17 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

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Keywords: programmable calculator, photointerpretation, forest inventory, variable plot cruising

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Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

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